SOME OF THE WAYS OF THE SLIME-MOULD

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A recent volume by Professor D'Arcy W. Thompson, bearing the terse title "Growth and Form," seems to me for the mycologist very suggestive, and to that extent, at least, one of the most useful among the books of later years. A paragraph from its pages might form the text for the discussions of the present paper. After developing at length and very clearly the various problems of tension, particularly as determined by molecular attractions, in liquids mass-tensions, surface-tension and their interactions, the author applies to *Æthalium*, a common slime-mould, the same principles applicable to so much water, assuming the myxomycete to have the same specific gravity, and both liquids placed for experiment under similar conditions. The paragraph, too long for quoting here, is noteworthy for two reasons: in the first place it presents, as is believed, the first citation of a slime-mould anywhere or at any time in a court of physical research; and in the second place, it is the first attempt, so far as I have noted, to refer the phenomena especially characteristic of the organisms in question to forces purely physical in nature—*i.e.*, to such as are familiar to the laboratories of purely physical science.

In these days of refined and beautiful physical research chemical and physical reactions are so interrelated that only the most accomplished expert in either or both fields may venture their mention, not to say discussion. The present writer makes no pretension; but there are in the life history of the slime-moulds certain peculiar facts, patent to ordinary observation, always worthy of study and, as it would seem, deserving, for thorough apprehension, not to say comprehension, all the help that physical science may afford. Professor Thompson's argument is very helpful, and yet—as illustrating the way of the slime-mould—permit me to summon the chief offender.

In 1876 Sachs in the one-time classic Physiology, discussing

protoplasm, refers to *Æthalium* and goes on to say: "It may happen that the substance creeps up the stems of plants a metre high and moves in the form of thin threads becoming collected above on large leaves as thick cakes the size of the hand. . . . There remains no doubt whatever that we have here to do with a structure which resembles in every detail the circulating protoplasm in living plant cells, only its mass is relatively extraordinarily large."

What we have to account for is the continuous stream that carries on until apparently the source of supply is exhausted, and accumulates at considerable elevation masses to be weighed in ounces, say, half a pound. It matters not that ascent was made a meter high; a centimeter high would do just as well, as far as that goes. I have photographed the same thing, eight feet above its base of operations, seated in the crotch of a vigorous bur-oak tree.

It is an old story. Men have been watching the phenomenon for two hundred years. Linné saw the mucors, as he called them, but was less a student. The greater man by far, the greatest mycologist the world has known, devotes pages to our problem. Fries says in Systema Mycologicum: "Often have my eyes, not without peculiar pleasure, watched the transition from weak beginnings to the perfection of complete development. The celerity in most of them is marvellous. At one time (for safe carriage) I deposited the plasmodium of a *Diachœa* in my hat, and within the space of one hour it had covered the greater part of it with its elegant white net work."

It must not be supposed that the outer head of the great Swedish student, no matter how brilliant the brain it covered, left the inner surface of the hat any less free from what, for cytoplasm, printers might term "objectionable matter," than would be the case did the hat cover the best brushed and tended human capital to be found in Chicago, and yet I have no doubt whatever of the accuracy of the Friesian narrative.

Permit me to cite a more recent observation: On the shore of an Iowa lake, not far from the water edge, I found one morning in July, 1909, a plasmodium emerging from beneath a boulder and

beginning the ascent of the overhanging face. Over the boulder I turned a tight, wooden box. In course of a few hours I found on the summit of the boulder, eight or ten inches high, as fine an *Æthalium* as anyone could wish to see. At the same time the vertical box wall showed plenty of belated, ascending streams, no doubt intended for a second *Æthalium* somewhere within the overturned box.

I have cited this last example because it seems to me to afford the simplest illustration we are likely to have, at least in the field, of the problem with which biophysics has to deal. The plasmodium, *i.e.,* the *Æthalium* of the physicist, in every case, we may assume, the same,—a mass of naked protoplasm, made up of myriads of minute, almost undifferentiated living cells, so associated as to be undistinguishable, at least in life,—is to the physicist a fluid, homogeneous, only slightly more dense than water, if at all; subject to desiccation, but not at all aquatic, requiring for translative movement, not a wet surface, not at all,—such perhaps in a measure prohibitive,—but probably best an invisible film, such as the moist atmosphere of summer might lend to any slightly cooler surface; too dry, doubtless as a matter of course, unfavorable. Of course, there can be no movement here as elsewhere, unless there is resistance, some point d'appui; so having considered the athlete, let us now consider the Matterhorn of his ambition.

Of the three instances of accomplishment, the second, the Friesian episode, may be now neglected as offering no special matters of distinction; if we are to overcome gravitation at all, the living stem of the growing plant would seem to afford highway most practicable, covered, we may suppose, with inequalities, points, projections of every sort as it surely is. This seems really of small advantage, if not a hindrance, to be surmounted; the glaucous glabrous shaft of *Impatiens* found in practice, useful for ascent as any other.

Let us study, then, the lake-side case. Here the journey was made around the blunt edge of an overhanging shelf; the action of gravity not only contrary to the general course of progress, but also in part (vertically) athwart it, as if to pull the climber from its hold. Nevertheless, as stated, and in abundant measure, the

journey was accomplished, no doubt on schedule time. Just why this journey was made it is hard to say, in view of the patent fact that for the plasmodium many another was quite open; much easier of accomplishment one would say, since other courses lay on the level, or even, gravity now favoring, downward amid recesses of rotting leaves and wood, whence the fountain welled. *Æthalium* is surely not geotropic, nor hydrotropic, since it now moved from these directions; neither was it heliotropic, nor even phototropic, in its turning; the gloom of the overshadowing box affected not the culmination of some overmastering push with which the movement started. Thermotropism there may have been, but the heat difference between the upper exposed portion of the boulder and that buried slightly in the forest mould could hardly have been great. In any case, light and warmth had been for days quite as tempting as in the hour the movement started; the impulse must have some other probably internal physiologic origin; doubtless some change molecular, since the outcome is maturity and fruit.

The biologist might go on to say that since the myxo is reproduced by spores distributed by air currents, or perchance the wind, only such fruits as rise above the general, local level have superior chances in the game of life; success is with those that climb; how the climbing is accomplished the biologist does not say.

But here the physicist may help us much. He steps in to say that every fluid drop or mass meets its environment by a skin, a film in tension, surface-tension, and this in case of your plasmodic stream holds fast sufficient to prevent gravity from pulling your hardy climbers from the Matterhorn, even from the overhanging shelf; while some internal, molecular changes in the cytoplasm itself, doubtless of physiologic import as the biologist suggests, sends the climber up and on to the fulfilment of physiologic function.

But *Æthalium* furnishes a special case. Not every myxo is by any means so rich either in material or equipment, but all aspire; generally speaking, all, even the most minute, show strange ambition, strive to reach upward or outward, if but a little way toward the open air. The behavior of *Æthalium* (most students say *Fuligo*) is strange enough, but the fruiting performance of some

of the more delicate species is more wonderful, more marvelous still.

The keen-eyed Swede, in what he could see with the lenses of a hundred years ago, never ceased his expressions of wonder; they are on every page. According to his theory, vegetation is always a matter of expansion, fruiting of contraction. And so when the plasmodium of some *Trichia, Craterium* or *Arcyria,* oozing up from its hidden nutritive base, began to spread before him in hundreds of thread-like streams covering the whole upper surface of some forest-shaded log or some bed of smouldering leaves, he was charmed; sat watching hour by hour, until over the whole field the threads began to break; rallying points not distant far from one another appearing along each filmy line, he was delighted; contraction succeeded expansion and he was satisfied. But when he returned perhaps on the following day to find that from every point a tiny stem had arisen, each surmounted by a glistening spherule large enough, unless perfectly erect, to bear the little stem to earth, his admiration knew no bounds; he said, "I find nothing more wonderful in all the world of plants."

We of today, seeing so much better and knowing so much more exactly the substance with which we have to deal, may, if we stop to reflect, be no less surprised than was our old-time master. We, far better than did he, know the nature of that thready stream, and may be moved perhaps to greater wonder when it ascends and stiffens several millimeters above the general level, and ends by bearing a sphere upon the expanded summit.

I am free to confess that I watched the procedure long before I learned its methods.

Any such mass of naked protoplasm as that we now discuss shows to ordinary observation a differentiated ectosarc, in appearance not very different from that which it incloses, but still distinct. This ectosarc, then, above occupies no doubt the field of surface-tension. As the physicist has taught us surface- and mass-tension are and remain in relative equilibrium as obedient to some internal force, the currents of the plasmodium push their varied way. But once in the physiologic history of the organism, the tension equilibrium is at any point disturbed in favor of the mass,

the ectosarc at that point yields; the inner cytoplasm follows, usually in direction normal to the basic surface, aided, of course, now by relatively increased surface-tension pressure on each side. As the ectosarc is thus carried up, it becomes, by desiccation perhaps, steadily fixed, from below upward, in position as in form, becomes indeed a capillary tubule closed entirely above by a film of ever-diminishing thickness. Against this continues the mass-pressure of the inner cytoplasm, spore-plasm it shall be, squeezed by increasing surface-tension from below, helped now no doubt by the capillarity of the hollow stem, until the upper remaining membrane, stretched to extreme tenuity by uniform pressure, becomes spherical in shape, and receives, so far as possible, all the cytoplasm from below, ready for conversion into spores.

That we have hit upon the correct solution of our problem is, in this case, further evidenced by the circumstance that sometimes the surface-tension at the base begins to lessen before all the spore-plasm has reached the summit and, equilibrium attained, part of the more vital endosarc remains below, lodged in the hollow stem. Here, with such success as may be, spore formation takes place as in the camera above, and the discerning taxonomist then writes, "stipe stuffed with spores, cells, capillitial threads, etc."

Such are some of the ways of the slime-mould, some of the devices by which it uses earth's various forces and conditions. The botanist tells us what he can see, viz., what his favorites *can* do, and possibly *why* they do it; the man of hydrostatics tells us how, once started, they effect their wonders; but of the molecular energy which still, over and over again, sends flood to fructification, and fruiting back again to flood, by constant, predetermined ways and paths, we still say little; that remains no doubt the general resultant of all those multifarious actions, reactions, attractions and repellings, which everywhere condition the manifestation of what we know and feel as life, and know and say no more.

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